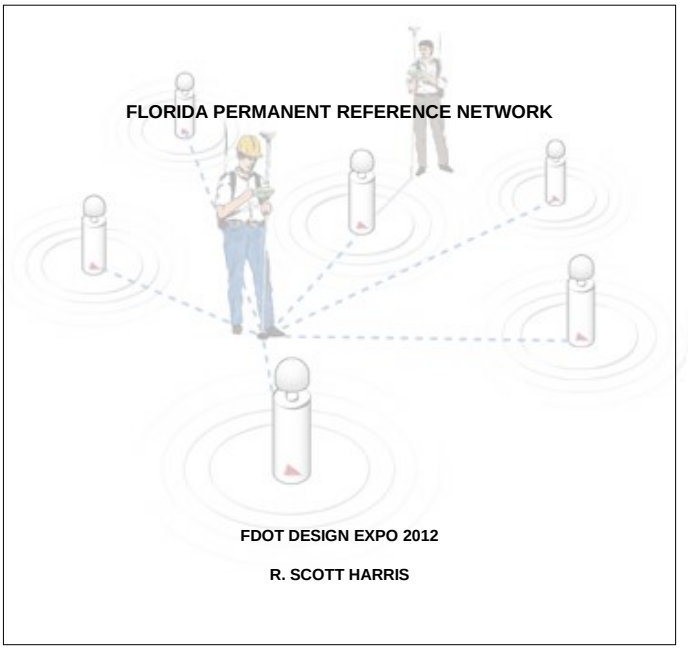


FLORIDA PERMANENT REFERENCE NETWORK

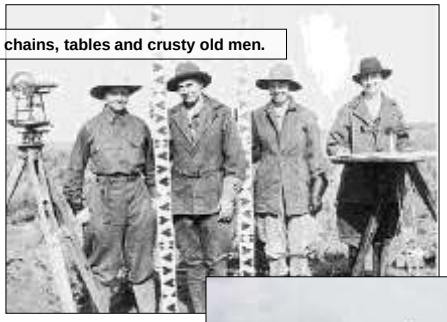
FDOT DESIGN EXPO 2012

R. SCOTT HARRIS

NICE PICTURE, BUT TELL ME MORE
Positioning

FPRN – Positioning Services
Surveying the "Old Way"

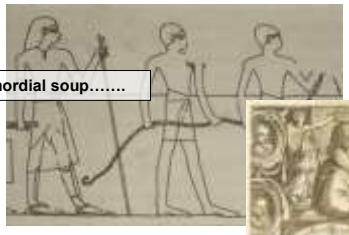
From chains, tables and crusty old men.



To black box VooDoo…..

FPRN – Positioning Services
Surveying the "Old Way"

Out of the primordial soup…….



GPS Surveying was born

FPRN – Positioning Services
Surveying the "GPS Way"

Developed by the US Department of Defense

Provides

Accurate Navigation 10 - 20 m
Worldwide Coverage
24 hour access
Common Coordinate System
Designed to replace existing navigation systems
Accessible by Civil and Military

FPRN – Positioning Services
Surveying the "GPS Way"

What is RTN? – How does RTN Work?

IN THE BEGINNING THERE WAS ONLY GPS

SENSORS WERE BIG AND BULKY

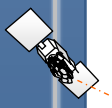
FPRN – Positioning Services
Surveying the "GPS Way"

What is RTN? – How does RTN Work?

$$\sum_{m=1}^{M}(\alpha_m\lambda_m\phi_{u,m}^k+\beta_m\rho_{u,m}^k) = \left(\sum_{m=1}^{M}(\alpha_m+\beta_m)\right)\cdot\left(\|\boldsymbol{x}_u-\boldsymbol{x}^k\|+(\boldsymbol{e}_u^k)^T\delta\boldsymbol{x}^k+c(\delta\tau_u-\delta\tau^k)+T_u^k\right)$$
$$+\left(\sum_{m=1}^{M}(\alpha_m-\beta_m)q_{1m}^2\right)\cdot I_{u,1}^{\prime k}+\left(\sum_{m=1}^{M}(\frac{1}{2}\alpha_m-\beta_m)q_{1m}^3\right)\cdot I_{u,1}^{\prime\prime k}$$
$$+\left(\sum_{m=1}^{M}\alpha_m\lambda_m N_m\right)+\left(\sum_{m=1}^{M}\alpha_m(b_{\phi_{u,m}}+b_{\phi_m^k})+\beta_m(b_{\rho_{u,m}}+b_{\rho_m^k})\right)$$
$$+\left(\sum_{m=1}^{M}(\alpha_m\bar{o}_{\phi_{u,m}^k}+\beta_m\bar{o}_{\rho_{u,m}^k})\right)+\left(\sum_{m=1}^{M}(\alpha_m\varepsilon_{\phi_{u,m}^k}+\beta_m\varepsilon_{\rho_{u,m}^k})\right)$$

1 POINT COULD TAKE HOURS TO SOLVE

GPS Principle : Range



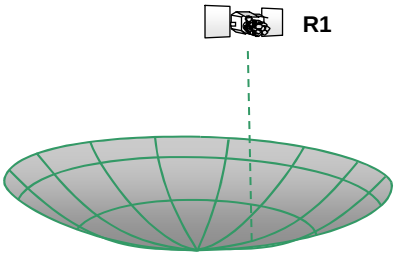
The satellites are like "Orbiting Radio Stations" broadcast timing data

Ranges (distances) are measured to each satellite using time dependent codes

Typically GPS receivers use inexpensive clocks that are much less precise than the clocks on board the satellites

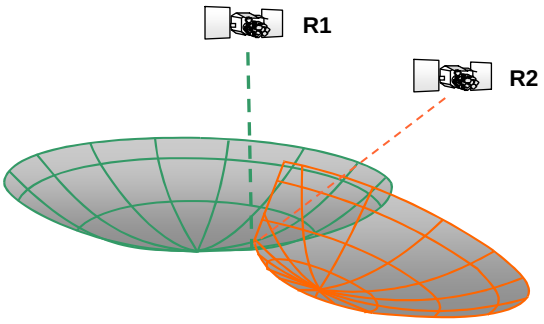
Range = Time Taken x Speed of Light

GPS Principle : Point Positioning



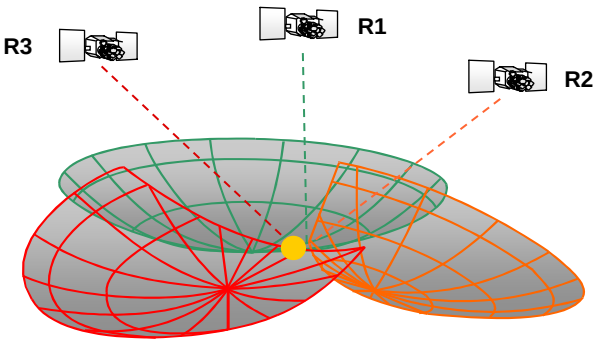
We are somewhere on a sphere of radius, R1

GPS Principle : Point Positioning



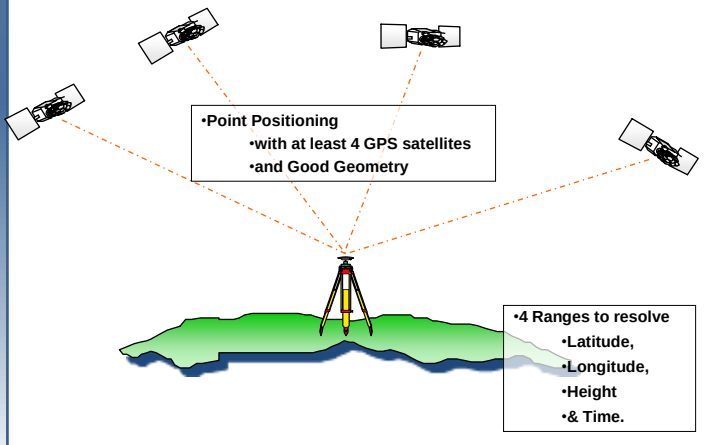
2 Spheres intersect as a circle

GPS Principle : Point Positioning



3 Spheres intersect at a point
3 Ranges to resolve for Latitude, Longitude and Height

Point Positioning



•Point Positioning
•with at least 4 GPS satellites
•and Good Geometry

•4 Ranges to resolve
•Latitude,
•Longitude,
•Height
•& Time.

In theory a point position can be accurate to 10 - 30m based on the C/A Code

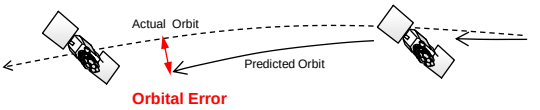
Error Sources

Like all other Surveying Equipment GPS works in the Real World

That means it owns a set of unique errors

- **Satellite Errors**
- **Observation Errors**
- **Sensor Error**
- **Multipath Error**
- **Geometry Error**
- **Operator Error**

Error Sources
Satellite



Satellite Clock Model

Though they use atomic clocks, they are still subject to small inaccuracies in their time keeping
These inaccuracies will translate into positional errors.

Orbit Uncertainty

The satellites position in space is also important as it's the beginning for all calculations
They drift slightly from their predicted orbit

Error Sources
Observation

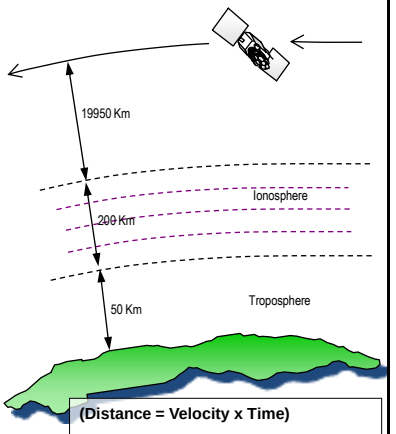
GPS signals transmit their timing information via radio waves

It is assumed that a radio wave travels at the speed of light.

GPS signals must travel through a number of layers making up the atmosphere.

As they travel through these layers the signal gets delayed

This delay translates into an error in the calculation of the distance between the satellite and the receiver



(Distance = Velocity x Time)

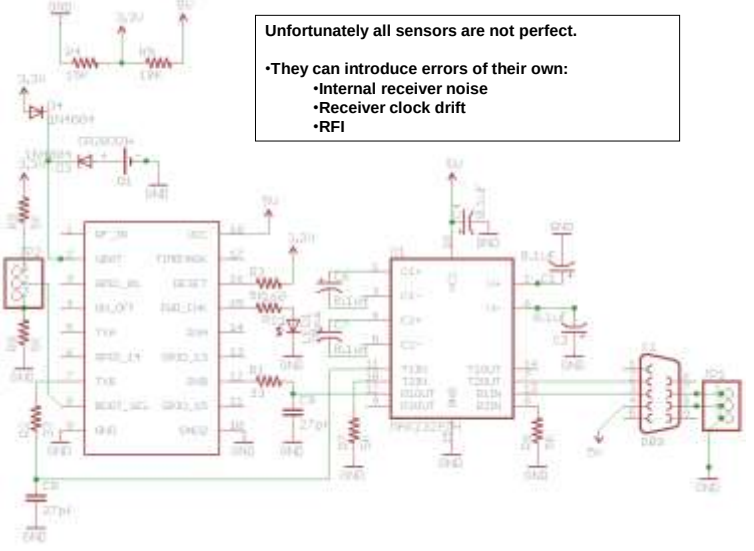
Consider an error in the timing.

- 1/10 second error = 30,000 Km error
- 1/1,000,000 second error = 300 m error

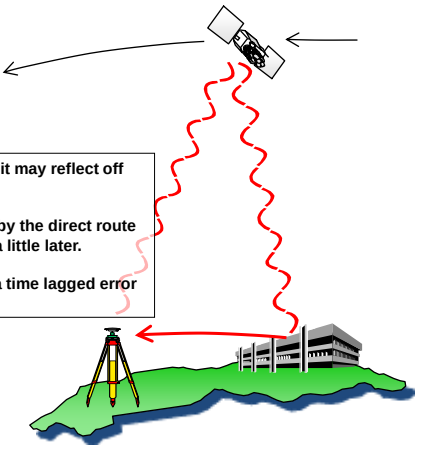
Error Sources
Sensor

Unfortunately all sensors are not perfect.

- **They can introduce errors of their own:**
  - **Internal receiver noise**
  - **Receiver clock drift**
  - **RFI**



Error Sources
Multipath

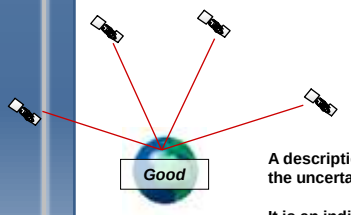


When the GPS signal arrives at earth it may reflect off various obstructions.

First the antenna receives the signal by the direct route and then the reflected signal arrives a little later.

The 2nd received signal has induced a time lagged error in your measurements.

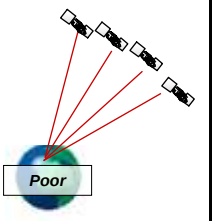
Error Sources
Geometry



A description of purely geometrical contribution to the uncertainty in a position fix

It is an indicator as to the geometrical strength of the satellites being tracked at the time of measurement

- GDOP (Geometrical),
  - Includes Lat, Lon, Height & Time
- PDOP (Positional)
  - Includes Lat, Lon & Height
- HDOP
  - (Horizontal)Includes Lat & Lon
- VDOP (Vertical)
  - Includes Height only



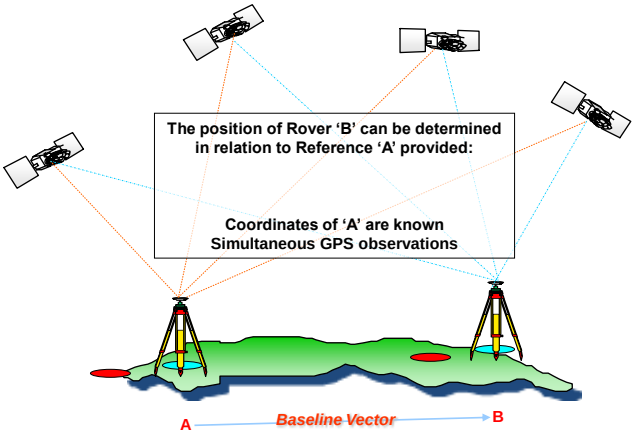
Error Sources

Operator

How do I
Improve my Accuracy?

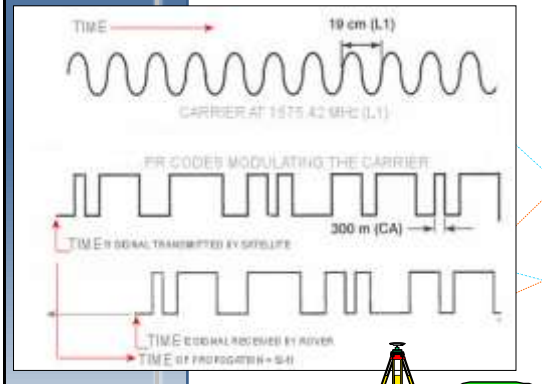
Use Differential GPS

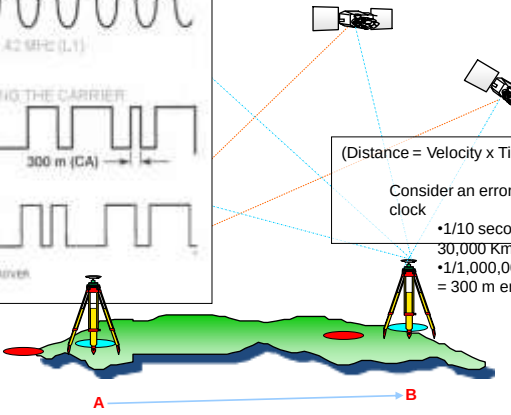
Differential GPS



Differential Positioning eliminates errors in the satellite and receiver clocks, minimizes atmospheric delays and improves accuracy 3mm - 5m

Differential GPS





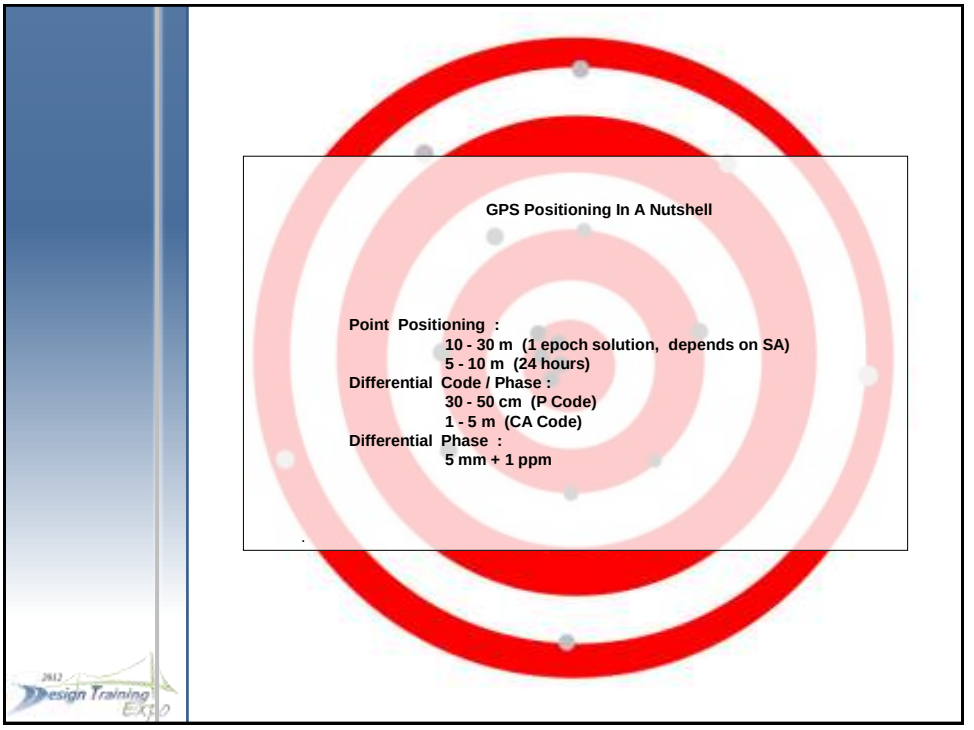
(Distance = Velocity x Time)

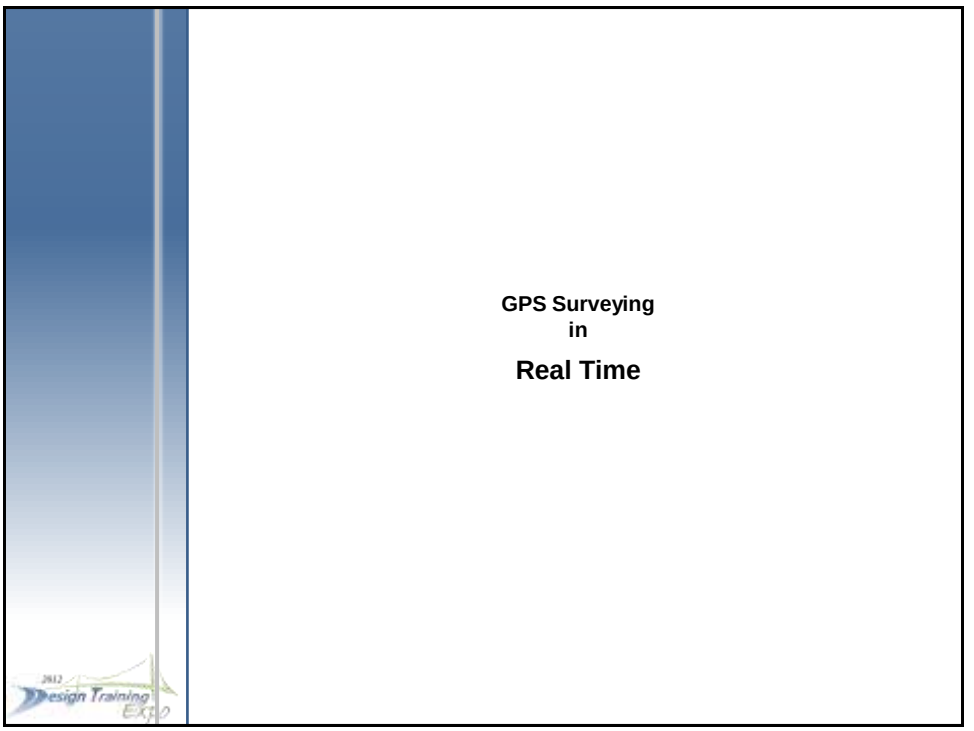
Consider an error in the receiver clock

- 1/10 second error = 30,000 Km error
- 1/1,000,000 second error = 300 m error

If using Code only (typically referred to as DGPS) accuracy is in the range of 30 - 100 cm

If using Phase or Code & Phase (typically referred to as RTK) accuracy is in the order of 5 - 10 mm + 1ppm


GPS Positioning In A Nutshell
Point Positioning :
10 - 30 m (1 epoch solution, depends on SA)
5 - 10 m (24 hours)
Differential Code / Phase :
30 - 50 cm (P Code)
1 - 5 m (CA Code)
Differential Phase :
5 mm + 1 ppm


GPS Surveying
in
Real Time

What is Real Time ?

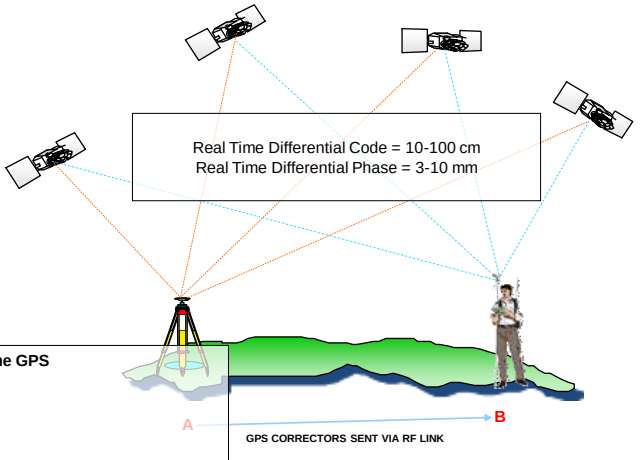
In a scientific sense Real Time can be defined as any action undertaken that results in an instantaneous response. Look at your watch. The time displayed is happening in Real Time.

RTK (Real-Time Kinematic) –a proven method of positioning in real-time at the cm-level.

Invented in the early 1990's.RTK makes GPS/GNSS a very efficient tool for some tasks such as construction staking, machine control, topographic surveys and many others where precise real-time positioning is valuable.

What is Real Time ?

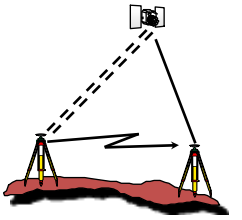
Traditional RTK is a single-baseline solution between a base station and a rover unit.



Advantages of Real Time GPS

- Good Accuracy
- No post processing
- Immediate Results
- One man operation
- One Base multiple rovers increases production
- Collect raw data
- Increased confidence
- Ease of operation

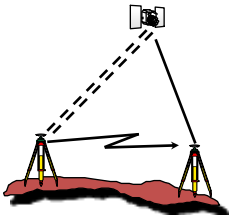
Real Time Differential Code (R-TIME Code)



At Reference Station
•Reference Station on a Known Point
•Tracks all Satellites in View
•Computes corrections for each satellite
•Transmits corrections via a communication link in either propriety format or in the RTCM format

At the Rover Station
•Rover unit receives the corrections via the communication link
•Rover position corrected by applying the received corrections
•ACCURACY 0.3m - 0.5m

Real Time Phase (RTK)

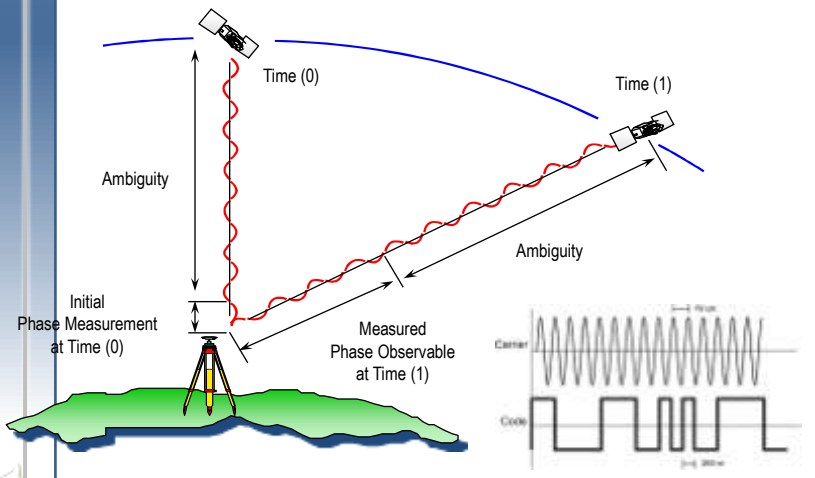


At Reference Station
•Reference Station on a Known Point
•Tracks all Satellites in View
•Transmits via a communication link GPS Measurements along with the Reference Station Coordinates

At the Rover Station
•Rover receives the GPS Measurements and Reference Station Coordinates via the communication link
•Rover undertakes computations to **resolve Ambiguities**
•ACCURACY 1 – 2cm + 2ppm

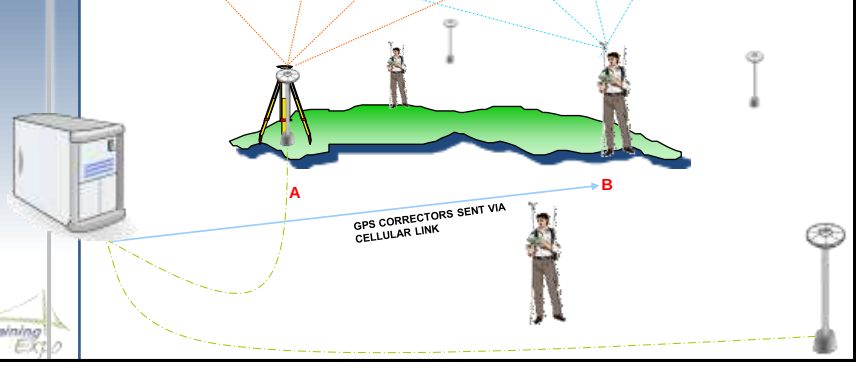
Initial Phase Ambiguity

Initial phase Ambiguity must be determined to use carrier phase data as distance measurements over time



What is a Real Time Network?

- **GPS RTK**
  - Typically temporary installation on a tripod
  - Reference for GPS operations in a small area (up to 30km)
- **Limitations of Single Base RTK**
  - High density of stations required for good coverage
  - No continuity in quality of service (accuracy, reliability, availability)
  - Higher costs and reduced productivity
- **Motivation for Network RTK**
  - Model and estimate distance-dependent errors
  - Main error sources: ionosphere, troposphere and satellite orbits
  - Provide network correction information to MANY rover users



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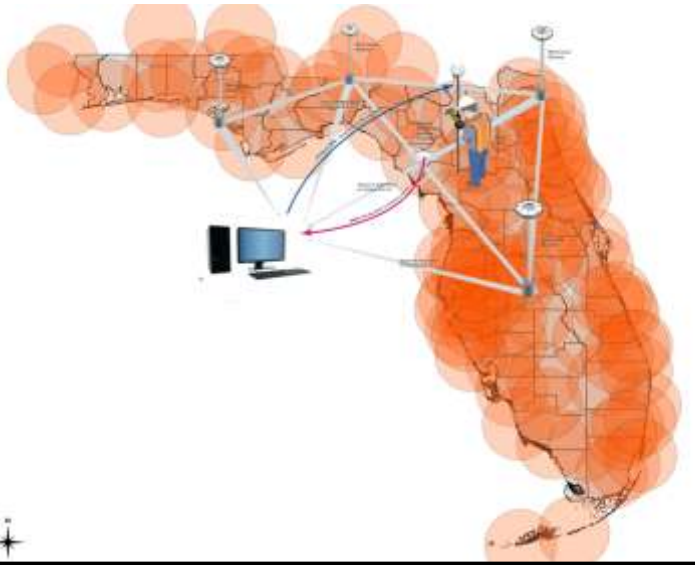
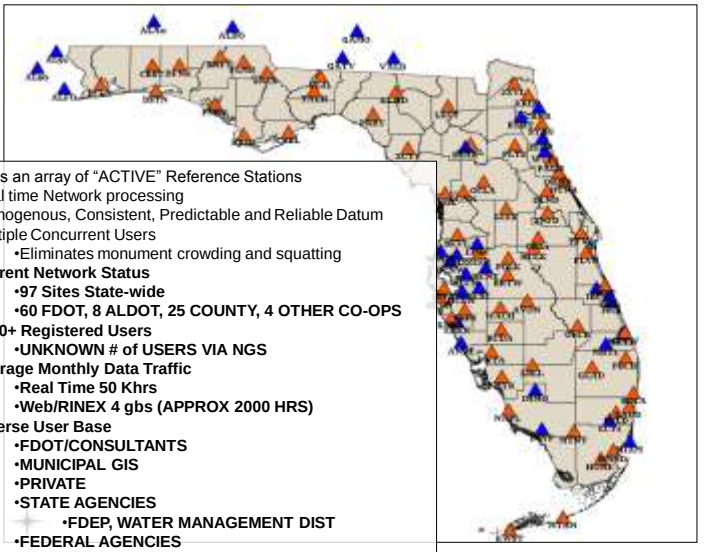


FLORIDA PERMANENT REFERENCE NETWORK



- Uses an array of "ACTIVE" Reference Stations
- Real time Network processing
- Homogenous, Consistent, Predictable and Reliable Datum
- Multiple Concurrent Users
  - Eliminates monument crowding and squatting
- **Current Network Status**
  - **97 Sites State-wide**
  - **60 FDOT, 8 ALDOT, 25 COUNTY, 4 OTHER CO-OPS**
- **1000+ Registered Users**
  - **UNKNOWN # of USERS VIA NGS**
- **Average Monthly Data Traffic**
  - **Real Time 50 Khrs**
  - **Web/RINEX 4 gbs (APPROX 2000 HRS)**
- **Diverse User Base**
  - **FDOT/CONSULTANTS**
  - **MUNICIPAL GIS**
  - **PRIVATE**
  - **STATE AGENCIES**
    - **FDEP, WATER MANAGEMENT DIST**
  - **FEDERAL AGENCIES**
    - **NASA, USACOE, USDA, BATFE, FAA**

FLORIDA PERMANENT REFERENCE NETWORK

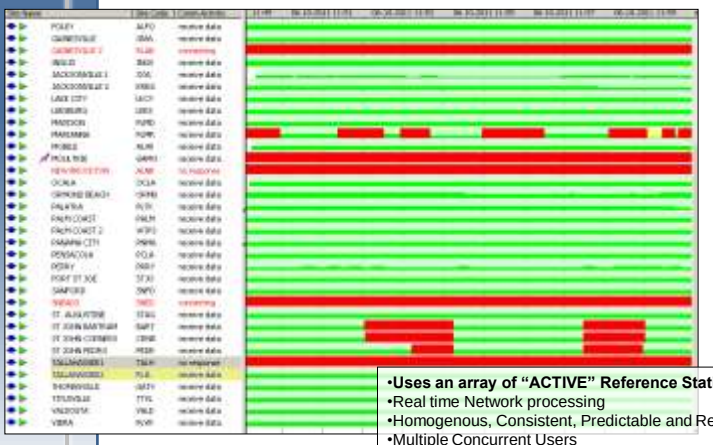
WHY?

BENEFITS

- Increased Coverage
- Improved availability
- Best Reliability
- Faster Rover initialisations
- Consistent high accuracy
- Higher productivity
- No local base station required
- Working on a common datum

Arrive on site, switch on and start working!

FLORIDA PERMANENT REFERENCE NETWORK



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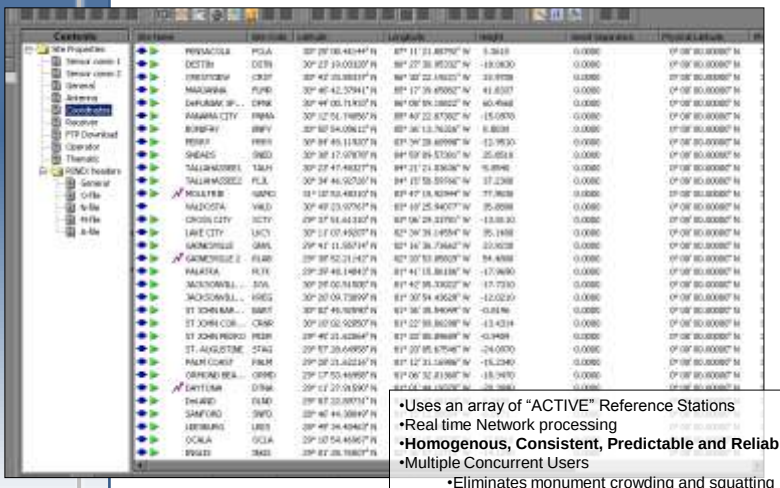

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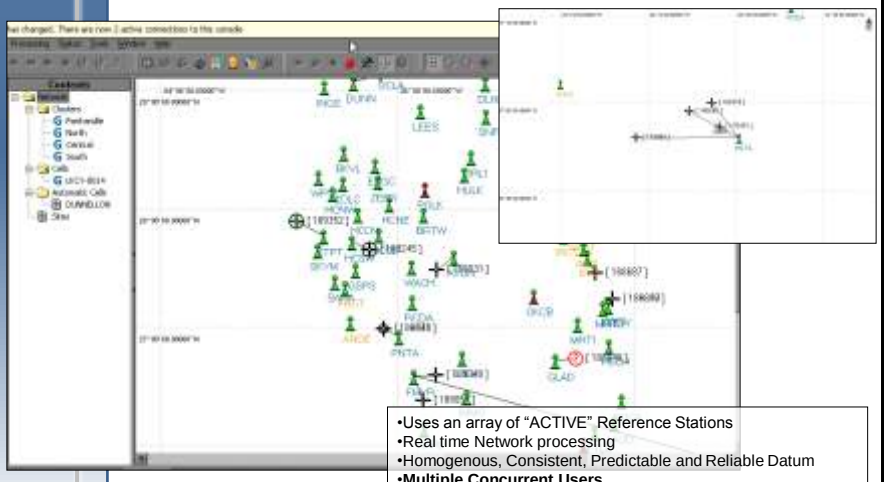

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GPS SURVEYING RUBBER

HITS THE ROAD

FPRN – Positioning Services

Today, GPS is a vital part of surveying and mapping activities around the world.

Global Positioning System (GPS) surveying is now seen as a true three dimensional tool.

When used by skilled professionals, GPS provides surveying and mapping data of the highest accuracy.

GPS-based data collection is much faster than conventional surveying and mapping techniques, reducing the amount of equipment and labor required.

The high productivity of RTK with its requirement for only a few epochs of data, means a single surveyor can now accomplish in one day what once took an entire team weeks to do.

For initial route finding or contour and detail surveys requiring accuracy at the several centimeter level, RTK IS well suited.

Real-time kinematic (RTK) positioning is similar to a total station radial survey. RTK does not require post processing of the data to obtain a position solution. This allows for real-time surveying in the field and allows the surveyor to check the quality of measurements without having to process the data.

FPRN – Positioning Services

The FDOT RTK Network is based on the National Spatial Reference System, which means that all coordinates are in the NAD83 datum and accuracy and compatibility should not be a problem.

This however, can work against users when all previous work was done on local coordinates or the area of previous control may carry local biases.

To overcome the clash of coordinate values, the process of “calibrating” to the existing control is used. This was not used as extensively via the base station method where the control point coordinates were the start of subsequent GPS work.

Most RTK network surveys should be done after a calibration to existing control. Even if the horizontal component doesn’t require a calibration, consider performing the vertical calibration. GPS solutions require the aid of a geoid model for elevations. In several areas around the state, the geoid model has a NOTICABLE differences from known elevations. If any known bench marks exist in the area; calibrate to them.

FPRN – Positioning Services


Building Construction


Utilities Sector


GPS Monitoring


Precise Vehicle Tracking


Emergency Services


Port Operations


Land Surveying


Machine Control


Agriculture

FPRN – Positioning Services

Land Surveying

FPRN – Positioning Services

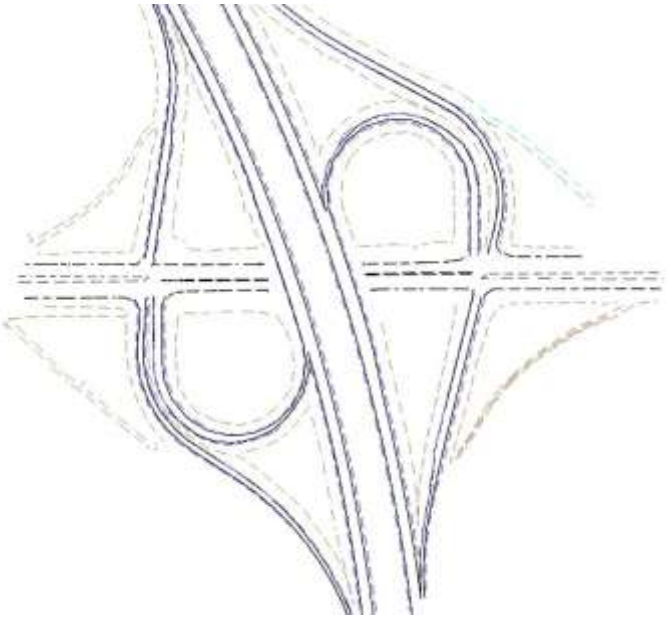
Route Surveying

Topography and cadastral surveying are the basic tasks of most land surveyors. With the constantly changing landscape, the need for precise, productive positioning is ever-present.

In performing a topographic survey, both accuracy and speed are vital. And when setting marks to create or re-establish cadastral and land boundaries, precise positioning is of the utmost importance.

FPRN – Positioning Services

Route Surveying



FPRN – Positioning Services
Route Surveying

Digital Terrain Model (DTM) is the basic building block of most surveys and is a three-dimensional representation of a surface.

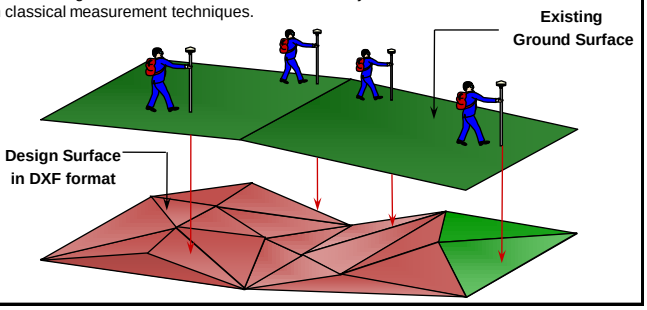
The purpose of DTM is to represent a topographic surface by a mathematically described surface. For this reason, it is necessary to determine base points described with three-dimensional coordinates.

DTM's are generated by the collection of points and are determined by various measurement methods.

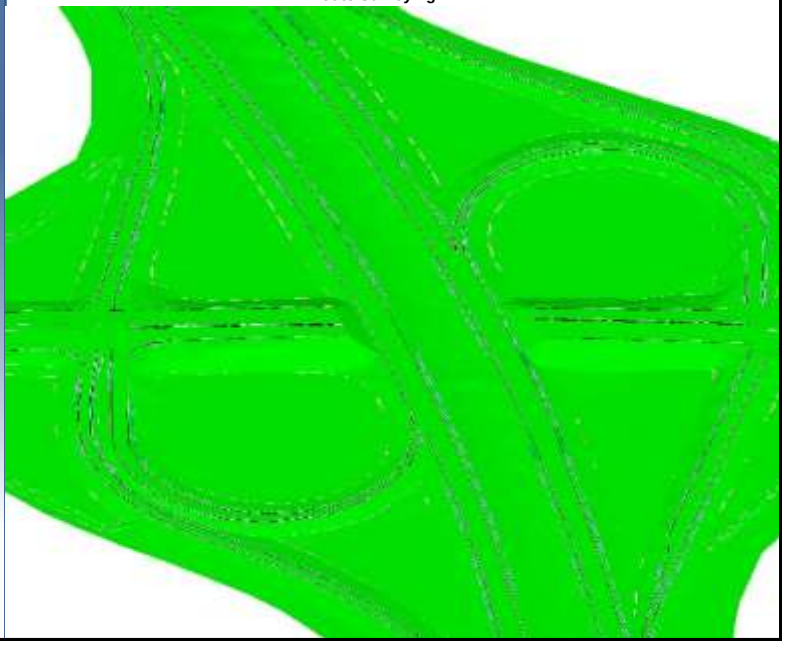
Real Time Kinematic (RTK) GPS is one of these methods.

Instant and definite measurements are obtained when RTK GPS methods are used.

Detailed points constituting the DTM can be measured more swiftly and accurately than classical measurement techniques.



FPRN – Positioning Services
Route Surveying



FPRN – Positioning Services

Route Surveying

Using RTK For Construction Staking

Real-time construction staking, like real-time surveying, can be a much better process than using other methods.

Having to process data after a survey with older technology takes valuable time and resources that don't need to be utilized anymore.

Using RTK (Real Time Kinematic) for construction staking is effective, and allows for real-time information and positioning so that the surveys and stake placement can be as accurate as conventional land surveying and done in less time.

Construction staking is a critical part of the building process, because it helps to identify everything from land grades and utilities to positioning for corners, structure walls, and other parts of the building as per the site survey.

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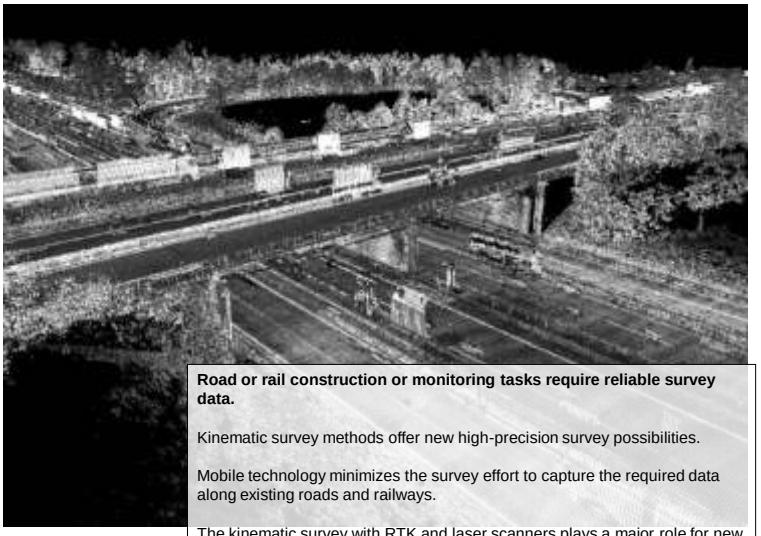
Mobile Mapping/Surveying



Road or rail construction or monitoring tasks require reliable survey data.

Kinematic survey methods offer new high-precision survey possibilities.

Mobile technology minimizes the survey effort to capture the required data along existing roads and railways.

The kinematic survey with RTK and laser scanners plays a major role for new possibilities of construction machine control and guidance based on the kinematic survey results.

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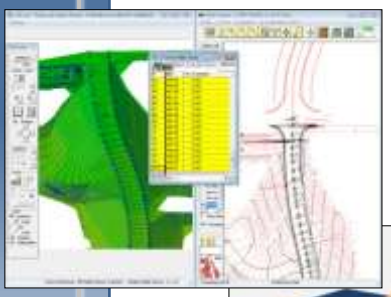
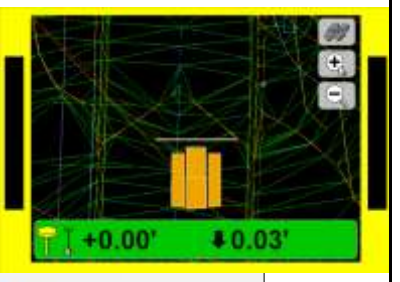
Machine Control





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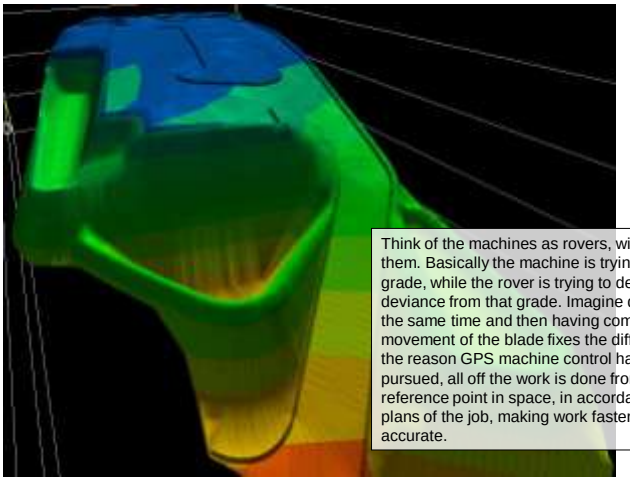
Machine Control

GPS machine control systems all have many things in common. Scrapers, excavators, blades, and even tractors all must use the same basic philosophy when utilizing GPS.



Think of the machines as rovers, with blades on them. Basically the machine is trying to attain grade, while the rover is trying to determine deviance from that grade. Imagine doing both at the same time and then having computerized movement of the blade fixes the difference. Thus the reason GPS machine control has been pursued, all off the work is done from the same reference point in space, in accordance to the plans of the job, making work faster and more accurate.

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Machine Control

A brief overview of some of the benefits GPS provides include:

•**Accurate Grade:** If all machines on site are GPS enabled, they simply run all day long, ACCURATELY, even with rookie drivers in the cockpit. The accuracy of the equipment ensures grade within tolerances, on the first pass, reducing work time, eliminating mid job survey crews, bumped stakes, and the like.

•**Job Management:** Continual, accurate, and complete jobsite information reduces the strain of managers, superintendents, and billing departments, as the proof is readily available for any discussion arising from the job.

•**Data Management:** Automated Reports, daily reports, and other data reports are generated by GPS Machine Control systems on a routine basis. These reports, are archived and distributed to all of the branches of your business to aid in work flow.

•**Billing Departments:** It's a perfect paper trail to prove activities completed, amount of material moved, and much more. Never have an argument or pay for their dirt again.

Cell Phones and Permanent Reference Stations with 20 Mile Radius

In large cities, metropolitan districts, mining operations, and other similarly large-scale operations, there is a need to have all parties working from the same system. The technology designed to handle this need is a Permanent Reference Stations . Basically put, a Permanent Reference Stations works like a mobile base station, transmitting error correction to rovers and machines in the field.

The major advantages of a Permanent Reference Stations over a local or portable base station are:

- •20 Mile Radius for accurate error corrections
- •GPS Systems can be used by hundreds - thousands of machines and rovers simultaneously.

All errors in the system are the same (inspectors, contractors, and surveyors)
GPS Base Systems Generate revenue and are cost effective for investors
Systems save contractors and surveyors annually Permanent GPS Encourages continued operations in a region externally.

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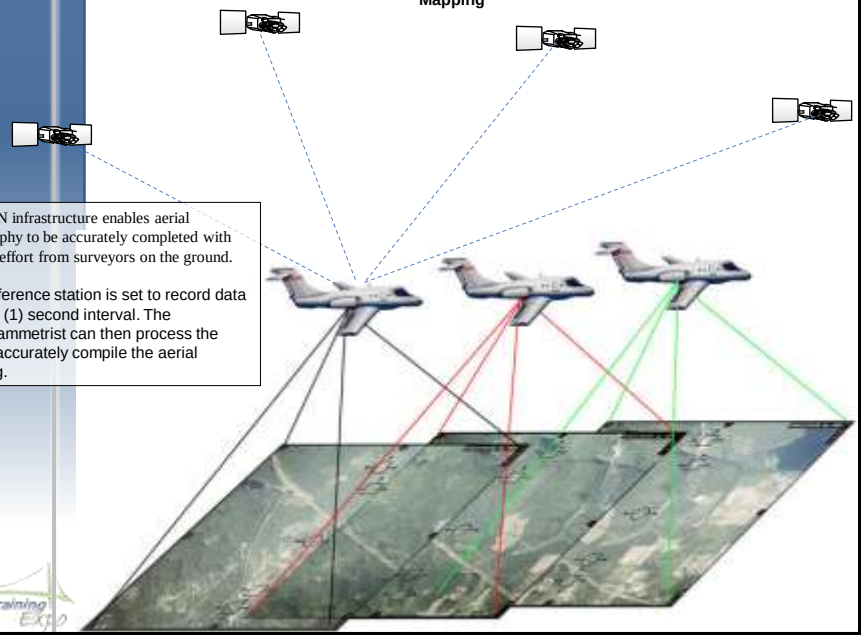
Mapping



An FPRN infrastructure enables aerial photography to be accurately completed with minimal effort from surveyors on the ground.

Each reference station is set to record data at a one (1) second interval. The photogrammetrist can then process the data to accurately compile the aerial mapping.

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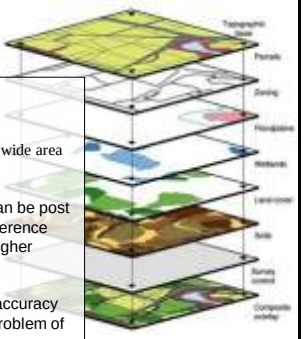
Mapping



GIS data collection initiatives are extremely enhanced with the FPRN infrastructure.

Data collection is performed more accurately and efficiently by having wide area coverage.

Data that is collected by hand-held "GIS" grade GPS receivers can be post processed with the RINEX data provided by each FPRN GPS reference station. Post processing to a nearby reference station provides higher accuracy with less occupation time.

A major advantage of an FPRN infrastructure is a common high accuracy reference frame by which all features are located. The inherent problem of data from different sources not matching in a GIS environment is eliminated by FPRN's dense array of Continuously Operating Reference Stations.

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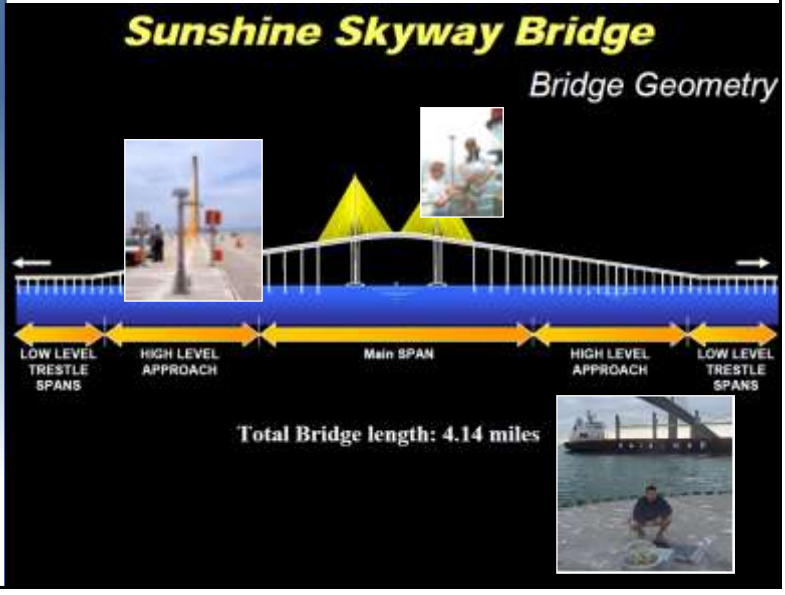
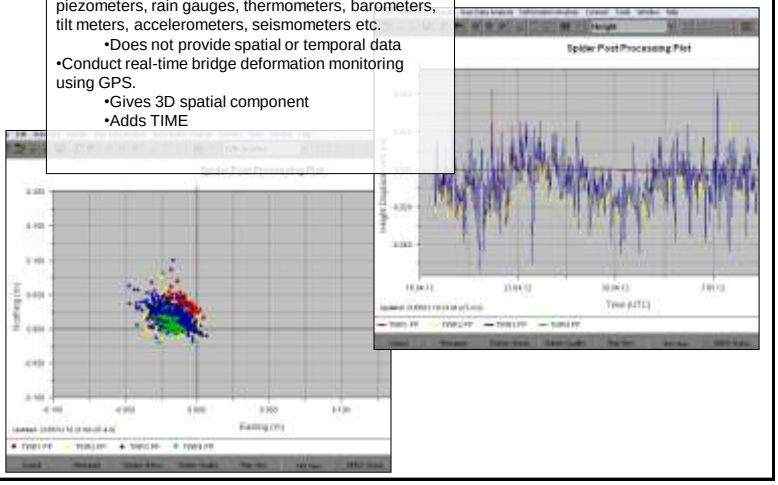
GPS Monitoring

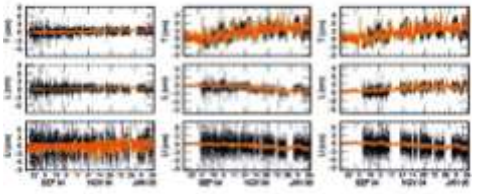


FPRN – Positioning Services
GPS Monitoring

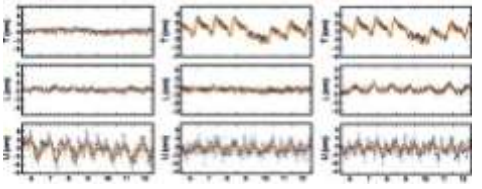
- Measuring bridge deformations and comparing it to expected theoretical values resulting from design, bridge safety can be assessed.
- Historically, geotechnical measuring devices measure non-georeferenced displacements or movements and related environmental effects or conditions. It includes the use of instruments such as extensometers, piezometers, rain gauges, thermometers, barometers, tilt meters, accelerometers, seismometers etc.
  - Does not provide spatial or temporal data
- Conduct real-time bridge deformation monitoring using GPS.
  - Gives 3D spatial component
  - Adds TIME



FPRN – Positioning Services
GPS Monitoring



The GPS determined changes in the position of the site on the center span (left), the north tower (center), and the south tower (right) Model predictions, shown in orange, were superimposed on graphs of the actual measurements for the up (U), longitudinal (L), and transverse (T) directions.



A subset of the GPS results for the site on the center span (left), the north tower (center), and the south tower (right), with the model predictions superimposed in orange.

FPRN – Positioning Services

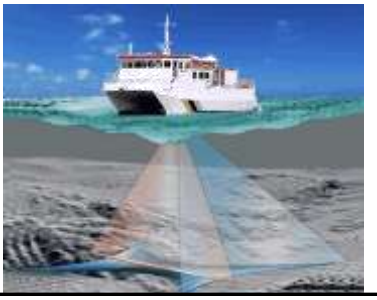
Hydro Surveying

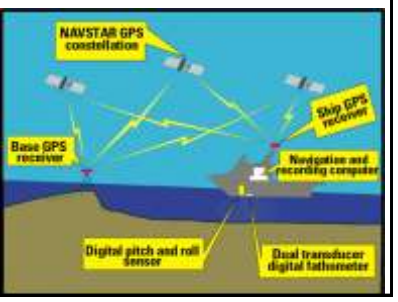
FPRN infrastructure provides real-time positioning capabilities to a wide geographic area to an accuracy level of 1 to 3 centimeters in the X, Y and Z axis.

The use of RTK GPS in Hydrographic surveying provides a vertical reference datum for all depth measurements and eliminates errors introduced from heave, vessel squat, and tidal fluctuations.

As a result, before and after dredging surveys are completed more accurately and more efficiently.

During survey or dredge operations, the use of RTK GPS water levels eliminates the need for shoreline support personnel to take tide staff readings. The accuracy of RTK also reduces the allowable over depth dredging which can save millions of dollars in dredging costs.





- http://www.myfloridagps.com/SpiderWeb/frmIndex.aspx